PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in or relating to a Temperature Responsive Indicator

I, DELMER THIEDE LANG, a Citizen of the United States of America, of 3717, Via Palomina, Palos Verdes Estates, State of California, United States of America, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a temperature responsive device of the type in which a temperature responsive fluid is confined within a thermal sensing element and means responsive to changes in pressure of the fluid with temperature, especially useful as a fire detector, particularly for aircraft.

In many places in aircraft, as for example, in reciprocating, turbo-prop and jet engines of airplanes, and cargo compartments thereof, it is desirable to obtain an indication of the start of a fire as by a perceptible signal, such as a bell or light, or to operate automatically fire extinguishing means, in accordance with such increases in temperature indicative of a fire or such overheating likely to start a fire. It is also desirable that such a device be capable of being subjected to an actual fire without destroying its function as a fire detector. Many devices and arrangements have been provided and used for such a purpose but no such device is sufficiently satisfactory in a number of particular respects, especially for particular uses, such as for engines of aircraft.

In accordance with the invention, however, there is provided, a fire detector which is not only relatively simple to manufacture, is rugged and requires substantially no maintenance in use, but which also performs the function of detecting a fire or incipient fire by responding to significant temperatures increases in an unusual manner so that it is especially useful for aircraft engines.

In my copending Application No. 7400/57 (Serial No. 823,133) there is disclosed a temperature responsive device comprising carbon disulfide confined within a hollow thermal sensing element connected to a pressure responsive means.

It is an especially important feature in accordance with the invention that the fire detector will give an indication of such a increase in temperature not only at one relatively small hot spot in the area where used, but also will give such an indication when the temperature of the whole, or large part, of the area in which used increases a significant amount to indicate a fire or incipient fire. In addition, in accordance with a further important feature of the invention, it is capable of withstanding a high degree of overheating resulting from an actual fire without damage to the fire detector, and for this purpose includes a means for relieving excessive pressures developed in the temperature responsive fluid.

Accordingly it is an object of the invention to provide a fire detector of the type which includes a confined temperature responsive fluid in combination with a means responsive to the changes of pressure in such fluid with changes in temperature thereof which will stand a high degree of overheating of such fluid without being damaged thereby.

It is a further object of the invention to provide a temperature responsive device of the type in which temperature responsive fluid is confined within a thermal sensing element and means responsive to changes in pressure of said fluid with temperature, which will give an indication, not only in accordance with a hot spot along the length of the thermal sensing element, but also when the temperature of a relatively large length thereof increases, and which will stand a high degree of heating without damage.

Other object and advantages of the invention will be apparent from the description thereof below.

In accordance with an embodiment generally described, the invention consists of a tem-

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perature responsive device comprising a temperature responsive liquid confined within a thermal sensing element and pressure responsive means responsive to the internal pressure of said liquid for giving an indication of temperatures of the liquid within the thermal sensing element in accordance with the temperature of a small volume of said liquid and in accordance with a larger volume of said liquid at a lower temperature than said small volume, means for indicating when the internal pressure of said confined liquid reaches a particular value which is the indicating internal pressure, said liquid being of such nature and being confined within said thermal sensing element and pressure responsive means under such conditions that said indicating internal pressure is reached by (1) an increase in temperature of a small volume of the liquid to such a temperature that the vapour pressure of the liquid produces such indicating internal pressure which is hydraulically transmitted throughout the rest of the liquid and to said pressure responsive means and (2) by a sufficient increase in the over-all temperature of the liquid that resulting thermal expansion thereof creates such indicating internal pressure, so that said device will give an indication when a small hot spot of the liquid anywhere within said thermal sensing element is heated to a temperature producing a vapor pressure hydraulically transmitted to said pressure responsive means as great as said indicating internal pressure and when a sufficient quantity of said liquid is heated to an average temperature, lower than said temperature produccing such vapor pressure, causing a sufficient resulting thermal expansion of the liquid to produce the indicating internal pressure.

With this arrangement as a fire detector capable of giving an indication either at a hot spot or when the over-all and average temperatures goes up to produce the indicating internal pressure, it is another important feature of the invention that means are provided for relieving excessive internal pressures resulting from overheating of the liquid at a predetermined value above the operating or indicating pressure and below a pressure which might damage the thermal sensing element or pressure responsive means.

In general, the fire detecting device in accordance with the invention is set to operate or give an indication when the internal pressure within the internal volume reaches a predetermined value. This internal pressure of operation develops either (1) when a hot spot along the tube reaches a temperature such that the vapor pressure of the liquid at such hot spot increases to this pressure or (2) when the over-all temperature of the liquid is such that the resulting thermal expansion of the liquid under liquid lock produces this internal pressure. Because the internal pressure of operation can be produced by either one of these conditions, the device is therefore especially useful as a fire detector particularly for aircraft engines.

It is another feature of the invention that the thermal sensing tube and fluid therein can stand a high degree of heating, if subjected to a fire, without impairing its function as a fire detector. This arises from the arrangement for relief of excessive internal pressure and from the further fact that such heating of the thermal sensing tube causes the major portion of the confined liquid to be forced into that part of the system near the Bourdon tube and pressure relief means where it is at a location removed from the fire. Thus the fire itself automatically causes a transfer of a major part of the liquid to a zone not subjected to such overheating. Moreover, in accordance with one particular aspect of the invention there has been discovered a particular material which can be used as the fluid and which is capable of withstanding an extraordinarily high degree of heating without impairing the functioning of the device as a fire detector.

The invention will be illustrated and explained by the description below of a specific embodiment thereof taken in conjunction with the accompanying drawings in which:—

Fig. 1 shows a device of the invention partly in cross-section.

Fig. 2 shows a portion of the elongated tube with a part thereof schematically enlarged to show a capillary vapor bubble in one part of the liquid within the tube.

Fig. 3 shows the schematically enlarged section of Fig. 2 illustrating the transfer of the capillary vapor bubble from the original location in the tube to the location at which the tube is heated.

Fig. 4 is another view similar to Fig. 3, schematically showing the transfer of the entire capillary vapor bubble to the hot spot of the tube.

Fig. 5 shows diagrammatically an arrangement for carrying out a method of filling the device with liquid.

Fig. 6 shows a plot of temperatures with pressure for a particular embodiment of the device.

Referring to Fig. 1, at 1 is shown an elongated flexible small bore tube of stainless steel connected to a Bourdon tube 2, through hole 5 in a stainless steel base member 3, circular in cross-section, and connected to opening 6 in the lower end of the Bourdon tube. The Bourdon tube is fixed in base member 3 as by silver brazing 7. Tube 1 is inserted in hole 5 and silver brazed therein as at 4.

Bourdon ttube 2, anchored in base member 3, is adapted to close contact points 8 and 9 with increase in pressure in the internal volume of Bourdon tube 2 and elongated tube 1 and to break electrical contacts 8 and 9 with

decrease in this pressure. As understood in the art, the making or breaking of contacts 8 and 9 can be used for making and breaking an electrical circuit which controls a perceptible signal such as a bell or light, or a device for extinguishing a fire. Thus the Bourdon tube will operate the contacts and control an electric circuit of an indicating device as a bell or light, as known in the art. Contact 9 is adjustable by screw 10 with respect to contact 8 to set the operating or indicating internal pressure, and, hence, the operating temperatures. Base member 3 carries an upwardly extending cylindrical portion 11 onto which is fitted housing 12 which carries binding post 113 to which contact 9 and its adjusting mechanism 10 is affixed. Three pieces 41, 42 and 43, of solid stainless steel are provided and are shaped to fit snugly within the Bourdon tube to fill up its volume while still allowing the Bourdon tube to move the contact point 8 with changes in internal pressure. The Bourdon tube 2 and contacts 8 and 9 are preferably hermetically sealed within the housing 12.

It is an important feature in accordance with the invention that a means is provided to relieve excessive internal pressure of the confined fluid when the thermal sensing extended tube 1 and fluid therewithin is overheated as by fire. For this purpose hole 5 communicates with hole 14 in the base member 3. Hole 14 opens directly on to the upper surface of flexible diaphragm 13 so that the pressure of the internal liquid is applied to to the upper face of this diaphragm just below the hole. Flexible diaphragm 13 is pressed firmly against the lower bottom surface 16 of base member 3 by gas under pressure in chamber 15, formed below the diaphragm 13 by stainless steel dome member 24. The diaphragm 13 and dome member 24 are silver brazed about the periphery of the bottom of base member 3 as at 23 and 25, respectively, forming a sealed chamber 15 for gas under pressure below the diaphragm 13. At ordinary values of internal pressure below the relief pressure, the top surface of diaphragm 13 fits so snugly against the bottom surface 16 of base member 3 that there is substantially no liquid therebetween and the pressure in chamber 15 is not transmitted to the liquid in the internal volume of hole 14, and, hence, the pressure in chamber 15 has no effect on the operation of the Bourdon tube.

In other words, the internal pressure of the liquid is independent of the pressure in the pressure chamber 15 until the internal pressure becomes great enough to move the diaphragm 13. This is accomplished by reason of the fact that the area of the liquid as applied to the top of diaphragm 13 at the bottom of hole 14 is sufficiently small that such small area of the diaphragm 13 is not flexible, but rigid, and the pressure of the gas in chamber 15 is not applied against the liquid in hole 14, but the pressure of the gas in 15 forces the diaphragm against the rigid bottom surface 16 of base member 3 so that the small area of diaphragm 13 below hole 14 rigidly confines the liquid and the greater gas pressure on the other side of the diaphragm is not transmitted to the liquid in hole 14. This obtains until the pressure of the liquid applied against the diaphragm 13 at the bottom of hole 14 exceeds the pressure of the gas in 15 and the diaphragm is forced downwardly into the gas in 15 and liquid flows through hole 14 between diaphragm 13 and the bottom surface 16.

The pressure in chamber 15 is set at such a high value above the internal pressures reached in normal operation as to relieve only any excessive pressure in the internal liquid at a point above which such pressure might damage the Bourdon tube or elongated tube 1. This is accoomplished by reason of the fact that diaphragm 13 will expand downwardly into chamber 15 when this relief pressure is reached so that the pressure in the internal volume applied to the Bourdon tube will not become any greater than the relief pressure of the gas in chamber 15. In the event of substantial heating of the extended tube 1 and fluid therein, as in the case of a fire, the high pressure developed within the extended tube 1 will force the liquid, against the gas pressure in chamber 15, through holes 5 and 14 and between the upper surface of diaphragm 13 and bottom surface 16 causing the diaphragm to expand downwardly providing a space for the liquid between the diaphragm and bottom surface 16.

Diaphragm 13 in this embodiment is about $1\frac{1}{4}$ inches in diameter and is made of a thin sheet of 0.005 inch thickness stainless steel, circular in cross-section having annular corrugations 17, 18 and 19 adapted to fit into annular grooves 20, 21 and 22 in the bottom of stainless steel base member 3. These annular corrugations in the diaphragm 13 are provided for the purpose of giving greater resiliency to the diaphragm, so that the diaphragm 13 may resiliently expand downwardly into pressure chamber 15 against the pressure thereof when the pressure of the liquid in the internal volume applied through opening 14 becomes greater than the gas pressure in chamber 15. The gas under pressure in chamber 15 may be introduced by way of pipe 26 sealed off as by pressure spot welding and silver brazing at 27. The gas used for pressure chamber 15 may be air or preferably nitrogen.

In use the base member 3 may be inserted in a hole 50 in a fire wall as shown at 44 and mounted thereon by affixing extending portions 45 of the dome 24 to the fire wall. With this arrangement the dome 24 faces the fire and the housing 12 and Bourdon tube are on the side of the fire wall protected from

the fire. Dome 24 may be protected from the fire by fiber glass insulation 56 within cover 47. Elongated tube 1 extends through a hole 48 in the upper part of dome 24 as shown. Preferably the elongated tube 1, base member 3, diaphragm 13, and dome 24 will be made of 18—8 stainless steel of type 321 or 347 so that the silver brazing may be accomplished most effectively.

Thus, it will be seen that in accordance with this embodiment of the invention the flexible extended tube 1 is adapted to be located and distributed about an area in which a fire is to be detected and that one end of the flexible tube 1 is connected to the base member 3 which carries not only the Bourdon tube 2 and the contact points 8 and 9, but also the diaphragm 13 and associated means for relieving excess pressure and for receiving a major portion of the confined temperature responsive fluid in the event of a high degree of overheating thereof within the extended tube 1. With this arrangement the base member 3 thus carrying the Bourdon tube and the pressure relieving means may be located at a position unaffected by the fire whereas the extended tube 1 may be in a location not only for detecting but where it may be subjected to a fire.

It is a desirable feature of the structural arrangement in accordance with this invention that the contacts 8 and 9 are substantially unaffected by vibration to which subjected in use, which might cause forced vibration of the Bourdon tube 2 carrying contact 8 at its outer end, such as the vibrations to which the device of the invention would be subjected in use as a fire detector for an aircraft engine. For this purpose, the Bourdon tube 2, even without any fluid therewithin, is made to have a natural frequency of vibration of contact point 8 to and from contact point 9 substantially greater than the vibration frequencies to which it will be subjected in use in connection with an aircraft engine. For this purpose, the Bourdon tube is made to have a natural frequency of vibration greater than 500 cycles per second. In the specific embodiment here shown, the length of the Bourdon tube 2 is only about 1¼ inches and is made by using only this short length of a very stiff Bourdon tube. The Bourdon tube of this specific embodiment being relatively short and very stiff is usd with the confined fluid at relatively high pressures.

It is another desirable feature of the invention that with the structural arrangement shown it is possible to obtain a relatively large movement of contact point 8 per unit change in temperature of the temperature responsive liquid in elongated tube 1. This arises from the fact that in accordance with the invention there is used a liquid having a high change of vapor pressure with temperature and a high rate of change of pressure resulting from thermal expansion per unit change in temperature taken in conjunction with the fact that the very stiff Bourdon tube as described above has substantially no change in volume with change of pressure of the confined fluid and the change of pressure of the confined fluid is therefore substantially all translated into movement of the Bourdon tube, and is not absorbed by an increase in the internal volume of the Bourdon tube.

In general, in accordance with the invention the confined liquid is preferably filled within the hollow thermal sensing element and pressure responsive means under the conditions of liquid lock. The thermal sensing element and pressure responsive means may be maintained at a given temperature and the liquid filled at this temperature under a pressure producing liquid lock. The thermal sensing element is then sealed off with the liquid confined therewithin and within the pressure responsive means under the condition of liquid lock, that is, with no vapor or gas present in the liquid. At some lower temperature a vapor bubble will appear within the liquid and usually the filling is effected at such temperature and pressure that a vapor bubble will be present in the normal temperatures of use. Under the conditions of liquid lock the internal pressure will depend on the vapor pressure at the hottest spot or on the pressure resulting from thermal expansion in accordance with the over-all temperature, whichever pressure is greater, thus, for example, the device though liquid locked can still operate in accordance with the vapor pressure at the hottest spot where the internal pressure is lower than this vapor pressure. However, if the hot spot increases in size the pressure due to thermal expansion may then exceed the vapor pressure so that the device then operates in accordance with the pressure derived from thermal expansion rather than the vapor pressure of the hot spot. At overall temperatures below the condition of liquid lock when a vapor bubble appears within the liquid, the internal pressure will depend on the vapor pressure of the liquid at the hottest spot thereof at least as large in volume as the vapor bubble.

Thus, usually under normal conditions of use the internal volume of elongated flexible tube 1 and Bourdon tube 2 is filled with a liquid having a small capillary vapor bubble at temperatures of the liquid below liquid lock. At such conditions of operation the Bourdon tube responds to the temperature at the hottest spot along the extended tube 1 in accordance with the vapor pressure of the liquid at the hottest spot. The vapor bubble remains in the liquid until the temperature of the liquid increases sufficiently to cause enough thermal expansion of the liquid to eliminate the vapor bubble and produce the condition of liquid lock. When the condition

of liquid lock is reached, that is, when the vapor bubble has been compressed out of existence, the internal pressure of the liquid then depends on (1) the pressure resulting from its thermal expansion in accordance with the overall temperature thereof, so that the device becomes sensitive susbtantially to the average temperature along elongated tube 1, or (2) the vapor pressure of the liquid at the hottest spot thereof, whichever pressure is greater.

It is thus an important feature, in accordance with the invention, that the fire detector will give an indication in accordance with a high temperature at a relatively small hot spot anywhere along the length of the elongated tube and also in accordance with a lower elevated temepratur over a sufficient length of elongated tube such that the average temperature of all the liquid is high enough to produce not only liquid lock of the liquid but also sufficient thermal expansion of the liquid to increase the internal pressure to the operating pressure. Thus this device will give an indication for a hot spot at a high temperature along the length of elongated tube 1 and also for a significant but lower increase in average temperature of the liquid throughout the region through which elongated tube 1 is distributed or placed.

The operation of the device at an over-all temperature thereof sufficiently low that the capillary vapor bubble is present within the liquid in the internal volume of elongated tube 1 and Bourdon tube 2 so that the internal pressure depends on the temperature of the hottest spot substantially the size of the vapor bubble along the tube will now be described. Referring to Fig. 2 there is shown a portion of the elongated tube 1 in section schematically enlarged to illustrate liquid 30 within the tube having capillary vapor bubble 31 therein. To make a hot spot at a portion of the tube, other than and displaced from the capillary vapor bubble 31, heat is applied at portion 32 as by the fire of a Bunsen burner 33 having flame 34 in contact with tube 1 at 32.

As flame 34 heats up a portion of the tube to make the hot spot at 32, the liquid thus heated exerts an increased pressure because of the increase of its vapor pressure with increase in temperature. This increased pressure is hydraulically transmitted through the liquid 30, confined in the internal volume, to capillary vapor bubble 31. Since the vapor in capillary vapor bubble 31 is in equilibrium with the liquid 30 at the lower temperature prevailing at the location of the vapor bubble 31, the resulting increase in pressure on the vapor bubble 31 causes condensation of the vapor in the bubble 31 and a new capillary vapor bubble 35 quickly begins to form at the heated portion 32 as the original capillary bubble 31 disappears as shown schematically in Fig. 3, and when a volume of liquid at least as great as the volume of the original vapor bubble is heated, the original capillary vapor bubble 31 completely disappears and is replaced by newly formed capillary vapor bubble 35 at the hot spot location 32, as shown in Fig. 4. Meanwhile, however, the pressure within the new capillary vapor bubble 35 is the vapor pressure of the liquid heated at the hot spot location 32 and this vapor pressure is hydraulically transmitted through the liquid in both directions from new capillary vapor bubble 35, particularly through the liquid in the tube into the liquid occupying the internal volume of the Bourdon tube so that this vapor pressure depending on the temperature at the hot spot 32 is transmitted into the Bourdon tube. Thus the vapor pressure of the liquid at any hot spot such as 32 is hydraulically transmitted to the interior of the Bourdon tube so that the whole system is sensitive to such a hot spot in accordance with the vapor pressure of the liquid at the hot spot at least as large as the vapor bubble volume, which pressure, of course, depends on the temperature of the liquid at the hot spot.

Thus, with a capillary vapor bubble within the liquid the internal pressure depends on the temperature at the hottest spot along the extended tube. The liquid at the hottest spot exerts an increased vapor pressure because of its increase in temperature, and this pressure is hydraulically transmitted through the liquid in the tube and applied against the capillary vapor bubble. As this pressure, thus hydraulically transmitted from the hot spot to the vapor capillary bubble, increases, the vapor in the bubble condenses and a new bubble forms at the hot spot, with the pressure in the entire internal volume depending on the vapor pressure at the hot spot. This vapor pressure is hydraulically transmitted by the liquid in the tube to the Bourdon tube. With further heating of liquid at the hot spot, the pressure rises in accordance with the vapor pressure of the heated liquid until the pressure of operation is reached. Thus, the vapor pressure of the vapor in the new bubble is hydraulically transmitted through the rest of the liquid in the system into the internal volume of the Bourdon tube and in this manner the Bourdon tube is operated in accordance with the vapor pressure developed at the hot spot hydraulically transmitted from the hot spot through the tube into the internal volume of the Bourdon tube.

Although with the vapor bubble present in the liquid the internal pressure will depend on the temperature of the hottest spot along the length of the extended tube, when a sufficient length of the extended tube is heated to a sufficiently high temperature that the thermal expansion of the liquid causes the vapor bubble to disappear and the con-

dition of liquid-lock occurs, the internal pressure will then depend on (1) the pressure resulting from the thermal expansion of the liquid in accordance with the over-all temperature of the entire quantity of internal liquid (2) on the vapor pressure of the liquid at the hottest spot thereof, whichever pressure is greater. Under this condition of liquid lock, the operating pressure willl thus then depend substantially on the average temperature of the liquid along the length of the extended tube or the vapor pressure at the hottest spot, whichever produces the greater pressure. Under the condition of liquid lock the operating pressure may be reached when a relatively large length of the extended tube is heated to an elevated temperature sufficient to cause that thermal expansion which will produce the operating pressure, even though the vapor pressure of the hottest spot is below the operating pressure. This elevated temperature will be a lower temperature than that hot spot temperature producing the same operating pressure. Thus, this device of the invention will not only respond to a hot spot along its length of sufficiently high temperature to create the operating pressure, but also to an elevated temperature along its length creating liquid lock and sufficient thermal expansion of the liquid to reach the operating pressure. In terms of its function as a fire detector, this means that it will respond to a small hot spot and also to an increased temperature throughout the region where the extended tube is located.

It is an especially advantageous feature in accordance with the invention that in use the device as shown in Fig. 1 may be so arranged that the extended tube 1 is placed in the region where fire will occur, whereas the base member 3 carrying Bourdon tube 2 and diaphragm 13 may be located in a position protected from the fire. With this arrangement, in the event of a fire overheating the fluid in extended tube 1, the substantial increase in pressure resulting will force the major portion of the liquid between the upper part of diaphragm 13 and the bottom part of base member 3 where it will be protected from such overheating. With this arrangement it will thus be possible to avoid such an overheating of the liquid by the fire as would create a sufficiently high pressure to burst the device.

In making the device of the invention it is desirable to substantially exclude all gases such as air, that is, the gases nitrogen and oxygen, and everything but the liquid because such gases provide an undesirable cushioning effect. That is, such gases provide a volume of gas merely obeying the gas law, expressed generally as the pressure times the volume is equal to the constant times the absolute temperature, instead of the law with regard to the relation between the vapor pressure of the confined liquid and its temperature. To exclude gases such as air, in accordance with the invention, gases are removed not only from the internal volume of the device but also preferably gases are removed from metals of the elongated tube and Bourdon tube and gases are dissolved in the liquid, by suitable outgassing heat treatment prior to or in conjunction with filling the internal volume of the device. It will be understood, of course, that the invention is operative even with a small volume of some such inert gas but that such volume of inert gas should be made as small as possible and avoided entirely if possible.

In the combination of the invention the ratio of the length of the elongated tube to the internal diameter will usually be greater than 500, 5000 or 10000 to 1. It is preferable that the tube be of such length with respect to the internal diameter that the vapor volume form a capillary vapor bubble when desired. By the term "capillary vapor bubble" is meant a bubble which when present in the elongated tube away from the end of the tube with liquid on each side will separate the liquid into two distinct portions. The bubble should be sufficiently large that it extends completely around the periphery of the internal surface of the tube to form a bubble at least part of which is a cylinder. For this purpose the diameter of the tube must be sufficiently small so that taken in conjunction with the particular liquid used and the particular metal of the internal surface of the tube the vapor will form such a vapor capillary bubble. This bubble may, under some conditions, appear at the end of the tube in which case it will not at this location actually separate the liquid into two distinct portions, but, if moved away from the end of the tube, will separate the liquid into two distinct portions.

In order to have such a capillary vapor bubble separating the liquid into two parts in the extended tube, in accordance with the invention, the diameter of the tube must be sufficiently small that such a capillary bubble will be formed and maintained. This internal diameter will depend upon the chemical nature of the particular liquid and the internal surface of the tube. Thus, the maximum diameter of the tube used in accordance with this aspect of the invention should not be greater than that which will form such a capillary bubble and maintain it with the particular liquid and its vapor and the particular internal surface of the tube. The capillary vapor bubble should be formed and maintained and the diameter of the tube should not be sufficiently great to permit the vapor bubble to allow the separated parts of the liquid to unite and thus provide a system in which the heated liquid will circulate under or by the bubble. On the other hand, the internal diameter of the tube should not be so small that hydraulic

transmission of the volume of liquid actually required to operate the Bourdon tube through the tube is difficult or impossible, because of an excessive or undue pressure drop within such small tube itself.

With regard to the length or volume of such a capillary vapor bubble, it will be noted that this length of the bubble determines the sensitivity of the device with respect to the size of the hot spot, that is, the length of the liquid in the tube at the hot spot, that must be heated to effect operation at temperatures below liquid lock. Thus, form the point of view of having the device sensitive to a small hot spot, that is a small length of tube, this length should be small. On the other hand, to avoid liquid lock and an internal pressure resulting from thermal expansion reaching the operating pressure at too low an over-all or average temperature, the length of the capillary vapor bubble will desirably be sufficiently large to provide an adequate temperature range to allow a desired range of heating of the liquid in the system without such thermal expansion of the liquid which will produce the operating pressure at too low average temperature.

In the combination in accordance with the invention as described, it is desirable to make the internal volume of the Bourdon tube as small as possible so that the device in accordance with the invention will be relatively insensitive to changes in temperature of the Bourdon tube itself. This may be done by reducing the volume of the Bourdon tube as described above by ways and means known in the art. In general, it is preferable in the combination of the invention that the volume of the Bourdon tube be less than about ten percent of the total internal volume of Bourdon tube and elongated tube.

It is important in accordance with the invention that the internal system of elongated tube and Bourdon tube be filled with liquid under the proper conditions to provide liquid lock and, when desired, the capillary vapor bubble at lower temperatures. To illustrate a method of filling the system with liquid, one specific method in accordance with this aspect of the invention will be described. To remove all gases such as air, that is, the gases nitrogen and oxygen, the metal parts of the Bourdon tube and extended tube are preferably placed under vacuum and treated in a manner known in the art to outgas these metal parts as much as possible. The liquid with which the Bourdon tube and elongated tube are to be filled is likewise preferably outgassed as much as possible by appropriate treating as known in the art.

In Fig. 5 is shown schematically an arrangement for carrying out this method in accordance with the invention. Here the extended tube 1 and base member 3 carrying Bourdon tube 2 and pressure chamber 15 filled with gas under pressure are shown with substantially all of the elongated tube 1, the Bourdon tube 2, and base member 3 immersed in a heated bath 30^1. This bath is maintained at the temperature at which the system is filled. At 31^1 is shown a vacuum pump connected to line 32^1 and line 36 having valve 37 leading into container 38 which holds the liquid 39 as shown. With valve 37 closed and valve 33^1 open a vacuum by means of pump 31^1 is applied to elongated tube 1 and Bourdon tube 2. The vacuum is preferably a high vacuum to remove gases as much as possible. Valve 33^1 is then closed and valve 37 is opened allowing liquid 39 under pressure to enter tube 1 and Bourdon tube 2 to entirely fill them with liquid without any vapour space at the bath temperature prevailing in tube 1 and Bourdon tube 2. This pressure of the liquid should be sufficiently high to produce liquid lock at the bath temperature of fill.

In general, the bath temperature should be sufficiently high that when the internal volume of extended tube and Bourdon tube are filled with liquid at a pressure above liquid lock and the liquid is cooled to a lower temperature a vapor bubble will be present in the liquid in the extended tube. For any given bath temperature and temperature to which the liquid is cooled after filling, the higher the pressure the smaller will be the capillary vapor bubble formed. For any given pressure of fill the higher the bath temperature, the larger will be the capillary vapor bullble for any given temperature to which cooled after filling. For any given value of operating pressure, the temperature of operation in accordance with the vapor pressure at the hottest spot will depend on the temperature of the particular liquid producing this value of vapor pressure. The temperature of operation resulting from thermal expansion under conditions of liquid lock will depend on the thermal expansion characteristics of the particular liquid in the particular system used. It will be understood that the pressure resulting from thermal expansion under liquid lock depends primarily on the thermal expansion of the liquid with temperature, lessened by its compressibility and the elasticity of the confining system.

Although in most cases in order to have the temperature of operation in accordance with the thermal expansion under conditions of liquid lock sufficiently low, it will be necessary to have a vapor bubble present under normal conditions of use, if the temperature of normal conditions of use is sufficiently low, the device in accordance with the invention may be used entirely in the liquid lock condition in which case the operating pressure may be reached either by an over-all temperture providing sufficient thermal expansion causing the internal pressure to reach the

value of the operating pressure or the operating pressure may be reached by virtue of the fact that the hottest spot of the liquid reaches a temperature such that the vapor pressure of the hot spot corresponds with the operating pressure.

Preferably, to assure that nothing but liquid is present in elongated tube 1 and Bourdon tube 2, the operation of exhausting by vacuum pump 31 and filling with liquid under pressure as described above, may be repeated as often as desired. It is also preferred to have the tube 1 and Bourdon tube 2 arranged in the bath so that the liquid will tend to run down into the Bourdon tube by gravity and any gas will travel up toward the end 34 to be more readily removed. It may also be found desirable to move the tube 1 and Bourdon tube 2 to assist such removal of gases as much as possible during the evacuation and charging with liquid. When the tube 1 and Bourdon tube 2 are thus filled with liquid under pressure, the end 34^1 of elongated tube 1 is sealed off. Preferably this is done by a spot welder which both flattens and welds the tube to effect a sealing weld. The tube is cut off a short distance beyond the weld, and the end then is heli-arc welded to form a sealing bead of the parent metal at the end of the tube.

When this device, in accordance with the invention, is cooled so that the elongated tube 1 drops in temperature sufficiently a vapor bubble forms within the tube as shown in Fig. 2. This device then filled by this method and as shown in Fig. 1 will be responsive to the hottest spot along the length of the elongated tube 1 in accordance with the vapor pressure of the liquid within the tube at this hottest spot and, above the conditions of liquid lock, will also be responsive to that over-all temperature or average temperature of the liquid causing sufficient thermal expansion to produce the operating pressure. It should be noted in this connection that the condition of liquid lock does not occur merely by heating a hot spot, but occurs only when the average temperature throughout the whole length of the system is sufficient to cause enough thermal expansion of the whole liquid to entirely eliminate any vapor space.

The invention will be further illustrated by a description of the following specific example which also illustrates a further particular aspect of the invention relating particularly to a specific combination of materials, that is, the metal of the elongaed tube and the chemical nature of the liquid in the internal volume which has been discovered makes it possible that the elongated tube be subjected to exceedingly high elevated temperatures without destroying or harming the functioning of the device as a fire detector.

In this specific example the elongated tube 1 was about four feet long of stainless steel tube having an outside diameter of 0.093 inches and an inside diameter of 0.023 inches in which the stainless steel was 18—8 type 321 and the confined fluid carbon disulfide. It is an important additional discovery in accordance with this embodiment of the invention that when the fluid is carbon disulfide, the extended tube may be subjected to such a high temperature as 2000° F. and the device is still capable of functioning as a fire detector.

The extended tube and Bourdon tube were filled with carbon disulfide at a pressure of 665 pounds per square inch with the whole device in an oil bath at 350° F. When carbon disulfide is used in devices intended to withstand very high temperatures it is especially desirable to exclude oxygen of air because evidence indicates there is apparently some decomposition of the carbon disulfide at very high temperatures in the presence of oxygen. When cooled to a uniform room temperature of 70° F. the carbon disulfide liquid has a capillary vapor bubble within the extended tube of about 10 inches long. At the intended use temperature of 250° F. for airplane engines, the capillary vapor bubble was about 3½ in length in the extended tube.

The characteristics of this device are illustrated by the plots shown in Fig. 6. Here temperatures are plotted with respect to internal pressure. Curve 100 on Fig. 6 represents the internal pressure with a temperature of the hottest spot of the liquid either under conditions such that a capillary vapor bubble is present and the liquid is not in the liquid lock condition or under liquid lock. This curve 100 corresponds with the vapor pressure curve for carbon disulfide up to the knee 105 where the curve is bent to merge with 101 because of the operation of the pressure relief device. Under the conditions of fill described above, for example, with the elongated tube 1 four feet in length at a substantially uniform temprature of 250° F. and the vapor bubble about 3½ inches long, the device responds to a hot spot at least about 3½ inches long in accordance with the vapor pressure of the carbon disulfide liquid as indicated by curve 100. The operating pressure for this device was set at 675 pounds per square inch, indicated for convenience by line 104 on Fig. 6, that is, contacts 8 and 9 will be closed when this internal pressure is reached and opened when this pressure drops below 675 psi. For operation in accordance with the vapor pressure of a hot spot, it will be seen that, for this operating pressure of 675 psi, the hot spot or vapor pressure temperature of operation is about 452° F.

With nitrogen in pressure chamber 15 of this device at a relief pressure of 935 pounds per square inch, should the temperature of a hot spot reach about 495° F. or above, the internal pressure would become greater

than this relief pressure. This is shown by that portion of the curve indicated as 105 leading into 101. It will be noted that the internal pressure thus leaves the vapor pressure curve 100 at knee 105 because of the pressure relief at about 935 psi.

Curve 102 is a plot of the internal pressure with the entire length of the extended tube heated to the uniform bath temperature here plotted. (It should be noted that the temperature plotted on vapor pressure curve 100 is the measured temperature of a hot spot and is different from the uniform temperature of the whole length of the tube plotted for this curve 102). It will be observed that, at a uniform temperature of approximately 326° F. of the whole length of elongated tube 1, the liquid becomes liquid locked, and, with an increase of this uniform temperature along the length of the extended tube as shown by curve 102, the pressure rises with increases in temperature in accordance wih the resulting thermal expansion such that the operating pressure is reached at the uniform temperature of 352° F. With further increase of this uniform temperature the pressure continues to rise until the pressure relief device bgins to relieve the pressure as shown at 103 merging with 101 with operation of the pressure relief device.

In accordance with this device, the operating pressure of 675 pounds per square inch can be rached either by heating a hot spot to the hot spot operating temperature of 452° F. or by heating the whole extended tube to the uniform temperature of 352° F. The pressure resulting from thermal expansion of the liquid and the pressure resulting from vapor pressure at the hottest spot are independent of one another, and the effective internal pressure within the Bourdon tube depends on which of these two independent pressures is the greater. It will be understood that this uniform temperature of 352° F. represents a particular average temperature of this same value. Moreover, above the condition of liquid lock, the operating pressure will be reached by any temperature distribution along the length of the extended tube 1 producing sufficient thermal expansion to produce the required operating pressure. The average temperature for any such temperature distribution will substantially correspond in all cases to the uniform temperature of 352° F. but may vary slightly therefrom depending on the actual temperature distribution along the length of the extended tube.

To test for a high degree of overheating without damage, the elongated tube of this device in accordance with the invention was heated to 2000° F. for one minute followed by cooling to room temperature of 70° F. for twenty separate tests, and each time after heating the Bourdon tube returned to the same position on cooling to 70° F. and the device was still found to perform satisfactorily as a fire detector. In another test the elongated tube 1 filled with the carbon disulfide as described was heated to 2000° F. for a little over 10 minutes and cooled back to 70° F. It was found the internal pressure at 70° F. was the same as before heating as indicated by the return of the Bourdon tube to the same position, and the device performed its functions as a fire detector.

The upper flat portions 103 and 101 of the curves corresponding to pressure relief may be shifted upwardly or downwardly by increasing or decreasing, respectively, the pressure of the nitrogen or other gas in pressure chamber 15. In other words, it will be understood that the maximum internal pressure may be controlled in accordance with the relief pressure in pressure chamber 15.

Curve 102 representing the pressure resulting from thermal expansion may be shifted either to the right or to the left by filling at a temperature and pressure corresponding to a point to the right or to the left of curve 102. For example, the liquid could be filled at a tmperature of 260° F. and a pressure of 600 pounds per square inch in which case curve 102 would be shifted to the left to pass through the points corresponding to these values. This new curve would have a slope and shape substantially the same as curve 102 and would intersect curve 100 at a temperature of approximately 240° F. corresponding to the over-all uniform temperature of liquid lock.

As another example, the liquid could be filled at a temperature of 450° F. and a pressure of 800 pounds per square inch in which case curve 102 would be shifted to the right to pass through the point corresponding to these values and would have a slope and shape substantially that of curve 102. This new curve would intersect the vapor pressure curve 100 at the temperature of about 430—440° F. corresponding to the uniform temperature of liquid lock for this condition of fill.

It will thus be seen that this makes it possible to make a device in accordance with the invention having an average temperature of operation under conditions of liquid lock within a relatively wide range of temperatures below the hot spot temperature corresponding to the operating pressure. For any particular values of temperature and pressure of fill the curve such as curve 102 is fixed for the device. Should it be desired, for example, to make a device having an average temperature of operation by pressure resulting from thermal expansion at 300° F. for an operating pressure of 500 psi the device can be filled at this temperature and pressure with the whole device at the uniform temperature of 300° F. The hot spot temperature of operation of this device will then be about 416° F. which is

the temperature at which carbon disulfide has a vapor pressure of about 500 psi. It will also be noted that for any given curve such as curve 102, the pressure of operation as represented by straight line 104 may be raised or lowered as by adjusting contact 9 from or to contact 8. For example, with curve 102 and curve 100 as shown, the pressure of operation could be 800 pounds per square inch in which case the temperature of operation in accordance with the vapor pressure would be about 475° F. and the temperature of operation in accordance with the thermal expansion would be about 365° F. average temperature.

It will also be understood that a device made in accordance with the invention may be used under such conditions that the confined liquid is under liquid lock at normal conditions of use and the device responsive to an operating pressure either (1) when the pressure resulting from thermal expansion reaches the operating pressure or (2) when the vapor pressure of the hottest spot reaches this operating pressure. For example, if the device whose characteristics are shown by the curves on Fig. 6 were used where the normal temperature is 330° F. so that the average temperature of the liquid is about 330° F. the liquid would be liquid locked and the operating pressure could be reached either by an increase of the average temperature to about 350° F. to produce the operating pressure of 675 psi by thermal expansion or by a small portion of the carbon disulfide liquid (a small hot spot) being heated to the temperature of 452° F., the temperature at which the vapor pressure is the operating pressure of 675 psi. It should be noted that under liquid lock, the vapor pressure of such a hot spot is transmitted hydraulically to the Bourdon tube and the spot may correspond to only a very small volume of liquid.

The specific embodiments given above are for the purpose of illustrating the invention, and it will be readily understood that the invention includes other modifications within the scope of the following claims.

WHAT I CLAIM IS:—

1. A temperature responsive device comprising a temperature responsive liquid confined within a thermal sensing element and pressure responsive means responsive to the internal pressure of said liquid for giving an indication of temperatures of the liquid within the thermal sensing element in accordance with the temperature of a small volume of said liquid and in accordance with a larger volume of said liquid at a lower temperature than said small volume, means for indicating when the internal pressure of said confined liquid reaches a particular value which is the indicating internal pressure, said liquid being of such nature and being confined within said thermal sensing element and pressure responsive means under such conditions that said indicating internal pressure is reached by (1) an increase in temperature of a small volume of the liquid to such a temperature that the vapor pressure of the liquid produces such indicating internal pressure which is hydraulically transmitted throughout the rest of the liquid and to said pressure responsive means and (2) by a sufficient increase in the over-all temperature of the liquid that resulting thermal expansion thereof creates such indicating internal pressure, so that said device will give an indication when a small hot spot of the liquid anywhere within said thermal sensing element is heated to a temperature producing a vapor pressure hydraulically transmitted to said pressure responsive means as great as said indicating internal pressure and when a sufficient quantity of said liquid is heated to an average temperature lower than said temperature producing such vapor pressure, causing a sufficient resulting thermal expansion of the liquid to produce the indicating internal pressure.

2. The device of Claim 1, wherein the pressure responsive means is responsive to the internal pressure of said liquid for giving an indication of temperatures of the liquid in accordance with a hot spot in the thermal sensing element and in accordance with a larger length of the element at a lower temperature than said hot spot, and having means operated by said pressure responsive means for closing an electrical circuit when said internal pressure reaches the particular value which is the indicating internal pressure.

3. A device according to Claim 1, wherein said thermal sensing element and pressure responsive means confine therewithin liquid such that (A) with the over-all temperatures of the liquid high enough to produce the condition of liquid lock; said particular value of internal pressure is reached (1) when the temperature at the hottest spot of the liquid produces such a vapor pressure hydraulically transmitted throughout said liquid to said pressure responsive means, and (2) when the over-all temperature of said liquid is sufficiently high that resulting thermal expansion produces such pressure, and, (B) with the over-all temperatures below the condition of liquid lock, a vapor bubble is present in said liquid so that said predetermined value of internal pressure is reached when the temperature of the hottest spot of said liquid at least as large in volume as said vapor bubble creates a vapor pressure equal to said indicating internal pressure hydraulically transmitted throughout said liquid to said pressure responsive means.

4. The device of Claim 3, wherein said device is adapted to give an indication of temperatures of the liquid within said thermal sensing element in accordance with a hot spot therewithin and in accordance with a

larger length thereof at a lower temperature than said hot spot.

5. A device according to Claim 1, wherein said thermal sensing element and pressure responsive means confine therewithin liquid having a capillary vapor bubble therein at temperatures of said liquid below liquid lock thereof, so that said internal pressure below liquid lock depends on the vapor pressure of the liquid at the hottest spot thereof, and above liquid lock depends on the thermal expansion of said liquid within said element and means associated therewithin accordance with the over-all temperature of said liquid or on the vapor pressure of the liquid at the hottest spot thereof, whichever pressure is greater, and means relieving internal pressures of said liquid in excess of the internal pressure of operation resulting from overheating of said liquid to avoid damage to said element or associated means.

6. A device according to Claim 5, wherein said means for relieving internal pressure includes means for applying the internal pressure of said liquid against one side of a movable member having a force applied to the other side thereof, and is adapted to relieve said internal pressure only when said pressure reaches a predetermined excessive value.

7. A device according to Claim 5, wherein the pressure responsive means are associated with a base member and are connected to thermal sensing element, the pressure relieving means being associated with said base member.

8. A device according to any of Claims 1 to 7, wherein the thermal sensing element is in the form of an elongated tube.

9. A device according to Claim 8, wherein said elongated tube has a small bore and a length greater than about 500 times the internal diameter.

10. A device according to Claims 7 and 8, wherein said elongated tube is adapted to be distributed about an area for detecting fire, and said base member, to which one end of said elongated tube is connected, is adapted to be placed in a position separated from said area in which fire is to be detected.

11. A device according to any of Claims 1 to 10, wherein the pressure responsive means comprises a Bourdon tube.

12. A device according to Claims 7 and 11, wherein the Bourdon tube is fixed to said base member to give an indication of temperature increase.

13. A device according to Claims 8 and 12, wherein the Bourdon tube is connected to said base member and to said elongated tube through a hole in said base member.

14. A device according to Claims 8 and 12 wherein said elongated tube is flexible and is adapted to be extended about a zone for detecting a fire therein, one end of said elongated tube is connected to said base member and to said Bourdon tube through a hole in said base member, and the temperature-responsive liquid being confined within said elongated tube and Bourdon tube so that said Bourdon tube is responsive to and gives indications of increase of temperature of said liquid within said extended tube.

15. A device according to Claim 7, wherein said base member has a surface to which a flexible diaphragm is affixed, a hole in said base member connects the face of said diaphragm in contact with said surface of said base member with said liquid so that the pressure of said liquid is applied against said face of said diaphragm, gas under pressure is on the other face of said flexible diaphragm so that when the pressure of said liquid reaches the pressure of said gas, said diaphragm will expand into said gas and liquid will enter the resulting space between said diaphragm and said surface of said base member to relieve pressure of said liquid.

16. A device according to Claim 5, wherein the pressure relieving means comprises means for applying the pressure of said liquid to one side of a movable member, such as a flexible diaphragm, to apply a force thereon tending to move said member away from said liquid; means resiliently applying a force to the opposite of said movable member, said movable member being prevented from transmitting said resilient force to said liquid, whereby said movable member tends to move in a direction opposing said resilient force when the internal pressure of the liquid reaches a predetermined excessive value and thereby relieves said excess pressure.

17. A device according to Claim 16, having gas on the opposite side of said member applying a gas pressure thereagainst at substantially the value of said predetermined value so that said member will move away from said liquid only when said predetermined pressure of said liquid is reached to relieve pressures of said liquid in excess of said predetermined pressure.

18. A device according to Claim 5, wherein the pressure relieving means comprises a flexible diaphragm, a small area of one side of which is connected to said liquid and subjected to the pressure of said liquid and a substantially larger area of the other side of which is subjected to the pressure of a gas so that when the pressure of said liquid reaches the pressure of said gas the diaphragm expands into said gas to relieve the pressure of said liquid.

19. A device according to Claim 18, including a rigid surface on the one side of said diaphragm against which the one surface of said diaphragm is pressed in contact with by

the pressure of said gas on the other side thereof.

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Fig. 1.

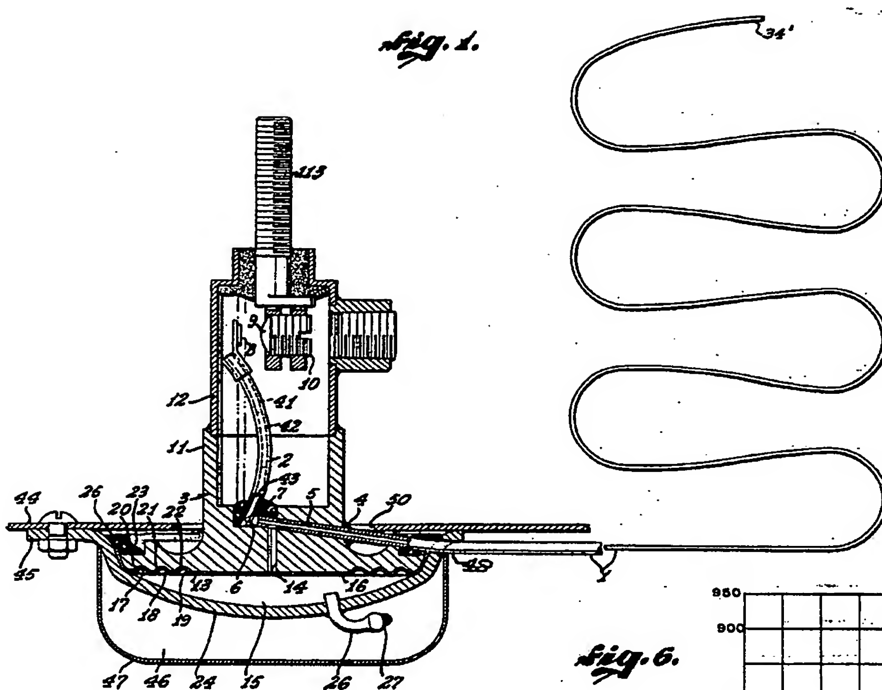


Fig. 6.

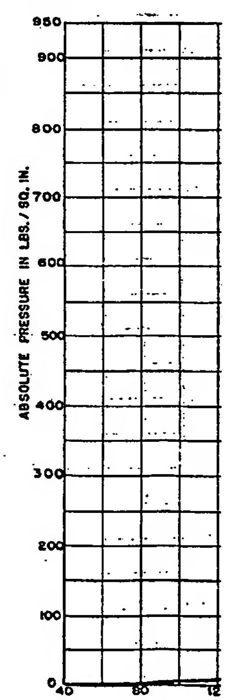
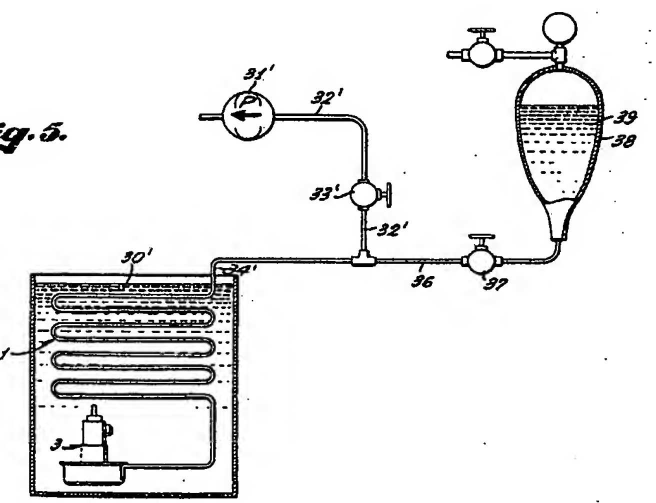


Fig. 5.



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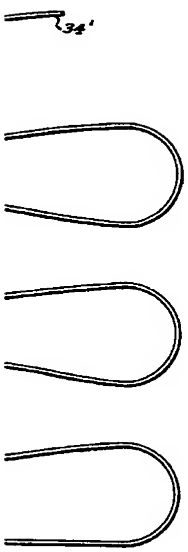


Fig. 2.

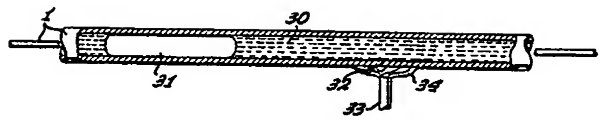


Fig. 3.

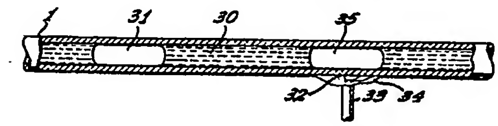
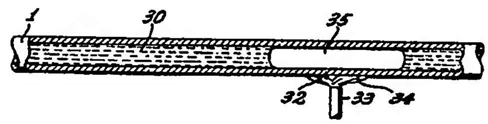


Fig. 4.



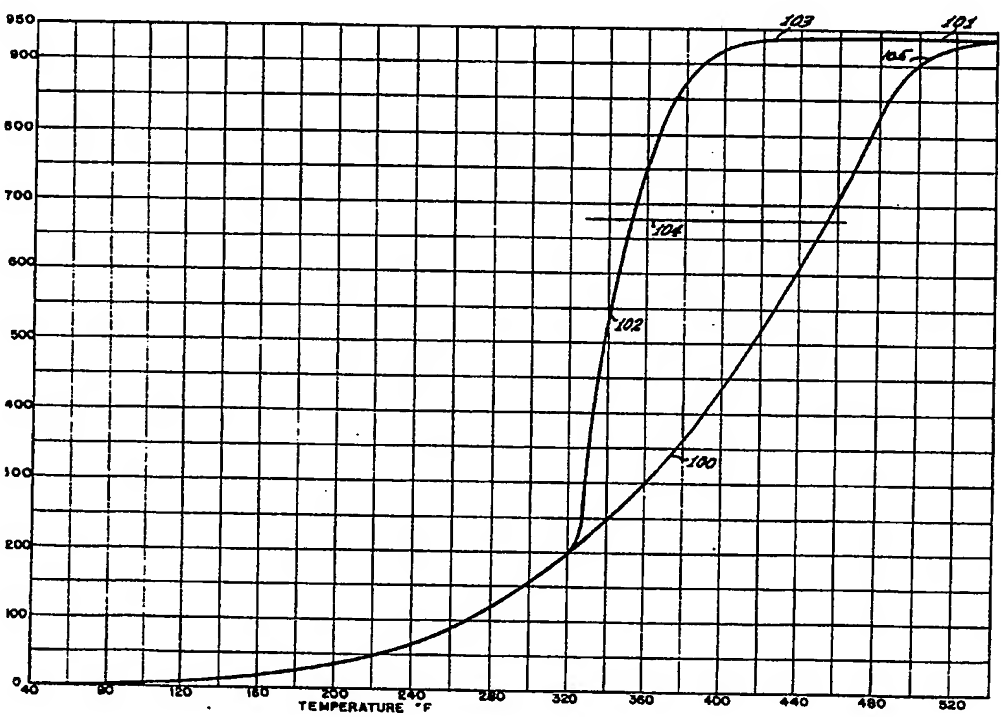


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Fig. 1.

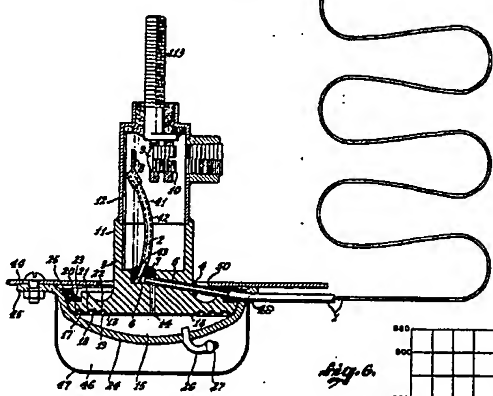

Fig. 2.

Fig. 3.

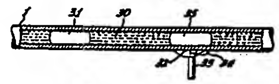

Fig. 4.

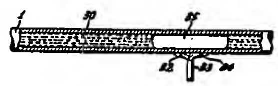

Fig. 6.

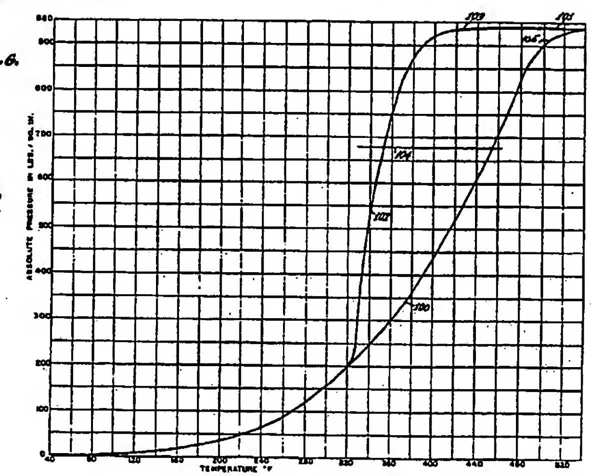

Fig. 5.